National Aeronautics and Space Administration

INFRARED TELESCOPE FACILITY'S SPECTROGRAPH OBSERVATIONS OF HUMAN-MADE SPACE OBJECTS

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Talk Layout

- How the data was collected and reduced
- Spectral Unmixing Model and how it was applied
- Results
- Conclusions

Why Collect the data

- **Spectral information on objects is important because:**
  - Knowledge of known objects helps to identify the unknown objects
  - Knowledge on the change in material surface properties helps to understand the space environment
  - Future materials for shielding, thermal, and identification

Data Collection

- **3.0-meter telescope: NASA's Infrared Telescope Facility (IRTF) located on Mauna Kea**

- **Observations taken using Spex Instrument**
  - 26-29 October 2006
  - 26-28 June 2007
  - 25-26 November 2007
  - 5 May 2008

- **Spex**
  - Low resolution with a slit width was 0.8″
  - spectral resolution ($\lambda/\Delta\lambda$) of ~93 across the entire 0.7 to 2.5 µm wavelength range

- **All GEO objects due to slower motion**

Data Collected

SSN Number	Common Names	International Designator	26-29 Oct. 2006	26-28 June 2007	25-26 Nov. 2007	5 May 2008	NF?
08476	SATCOM 1	1975-117A	X				Yes
08832	TITAN 3C TRANSTAGE DEB	1976-023J				X	Yes
11669	OPS 6393 (FLTSATCOM 3)	1980-004A	X				Yes
11964	GOES 4	1980-074A	X				Yes
12855	SBS 2	1981-096A		X			Yes
13984	SATCOM 1R	1983-030A				X	Yes
14234	ARABSAT 1DR (TELSTAR 3A)	1983-077A	X				No
14421	INTELSAT 507	1983-105A	X				No
15385	SPACENET 2	1984-114A	X			X	No
15826	TELSTAR 303	1985-048D	X				No
19550	IUS R/B (2)	1988-091D			X		Yes
20570	NEWSAT-1 (PALAPA B2R)	1990-034A			X		Yes
21641	IUS R/B (2)	1991-054D		X	X	X	Yes
21648	COSMOS 2054 DEB	1989-101G		X			Yes
22316	IUS R/B (2)	1993-003D		X			Yes
23615	IUS R/B (2)	1995-035D			X		Yes
25000	TITAN 3C TRANSTAGE DEB	1968-081G				X	Yes
25126	HGS-1 (ASIASAT 3)	1997-086A	X				Yes
25645	SL-12 R/B (2)	1999-010D		X		X	Yes
29014	EKRAN 2 DEB	1977-092K	X				Yes

Data Reduction

- **Used Spextool an IDL program**

- **Necessary calibration steps**
  - flatfield correction
  - wavelength calibration
  - defining apertures for extraction
  - tracing emission of the object across the array
  - extracting 1-D spectra

- **Standard stars and solar analogs were used to extract the atmospheric features**

Laboratory Data

- **Data collected using ASD Field Spectrometer**

- **Covers 0.3 to 2.5 microns**

- **Resolution of 10 nanometers at a wavelength of 2 μm and 717 channels**

- **300 common spacecraft materials are in the database: Limited number used**
  - Solar Cell MT
  - Solar Cell Polysat
  - Solar Cell at 0 deg phase
  - Solar Cell TRMM
  - Inconel (nickel-chromium superalloy)
  - Carbon Epoxy
  - Anodized Aluminum
  - White Paint
  - Aluminum Beta Cloth
  - Exposed White Paint
  - Aluminized Kapton
  - Multi-Layer Insulation— Kapton

Spectral Unmixing

- **Constrained Linear Least Squares (CLLS) model with the application of unmixing reflectance spectral data of orbiting objects**

- **Combined spectra can be added linearly**

$$S_{combined} = \sum_{i=1}^{n} p_i B_i S_i + N$$

where p_i is material proportion of the full spectrum, and S_i is the spectrum of that material, and B_i, is the orientation coefficient plus some noise, N

- **Using Vector Math, the above becomes:**

$$S_{combined} = SA$$

- **But S is not square so you need psuedo-inverse to solve for A**

Spectral Unmixing

- **Psuedo-Inverse yields:**

$$(S^T S)^{-1} S^T S_c = A$$

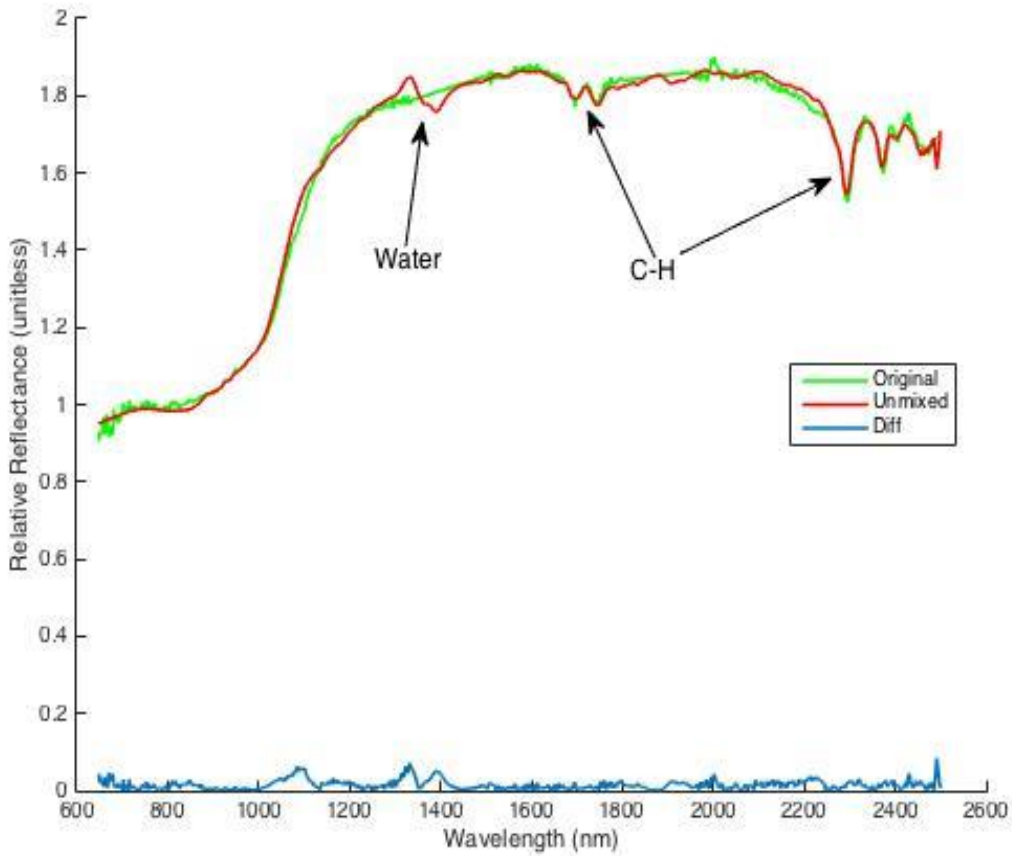
where S is the spectrum, S_c is the combined spectrum, S^T is the transpose

- **This can lead to negative proportions which is impossible: used a modified Lagrange multipler method to constrain the problem**

- **Error calculations is:**

$$Error = \frac{\sqrt{S_{diff}^T S_{diff}}}{\sqrt{S_c^T S_c}}$$

Results: NEWSAT 1



Error: 1%

SSN	Central Wavelength (nm)	FWHM (nm)	Central Wavelength model (nm)	FWHM model (nm)
ssn20570 (Nov2007)	1700	21	1699	23
ssn20570	1740	20	1745	30
ssn20570	2290	32	2291	47
ssn20570	2370	18	2369	23

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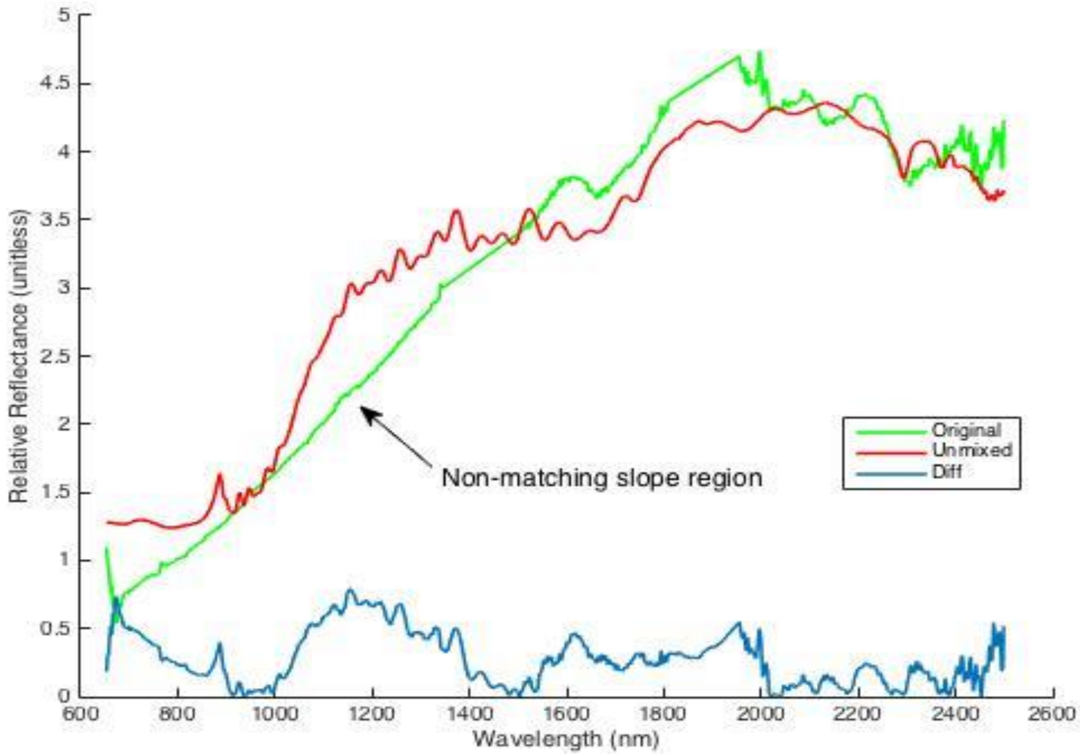
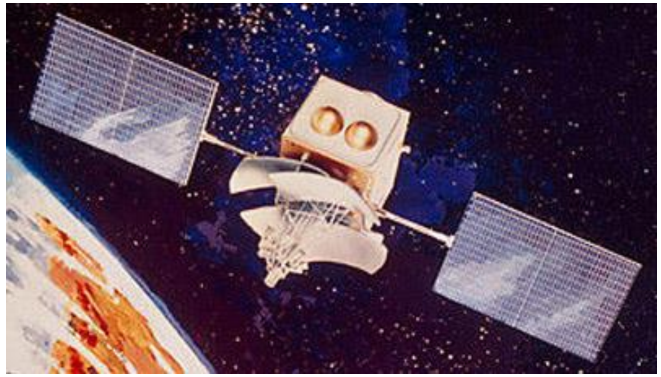
Results: Satcom 1

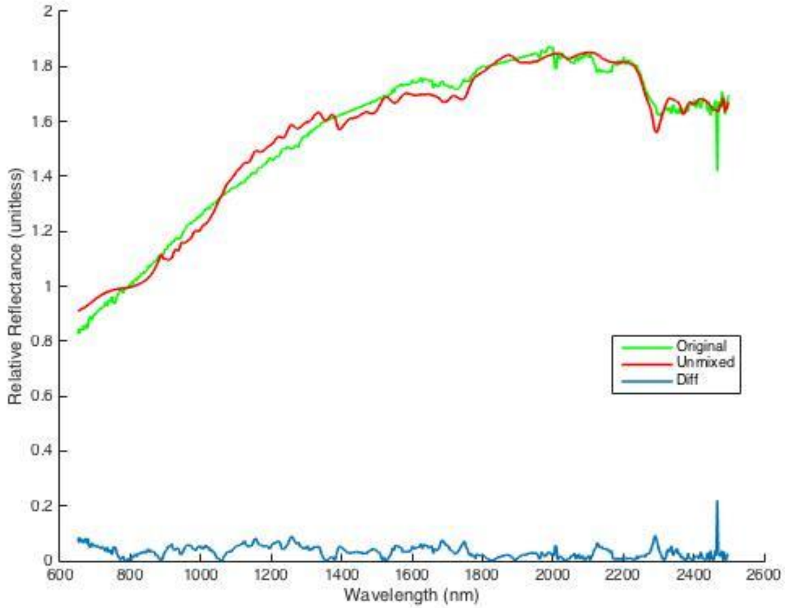


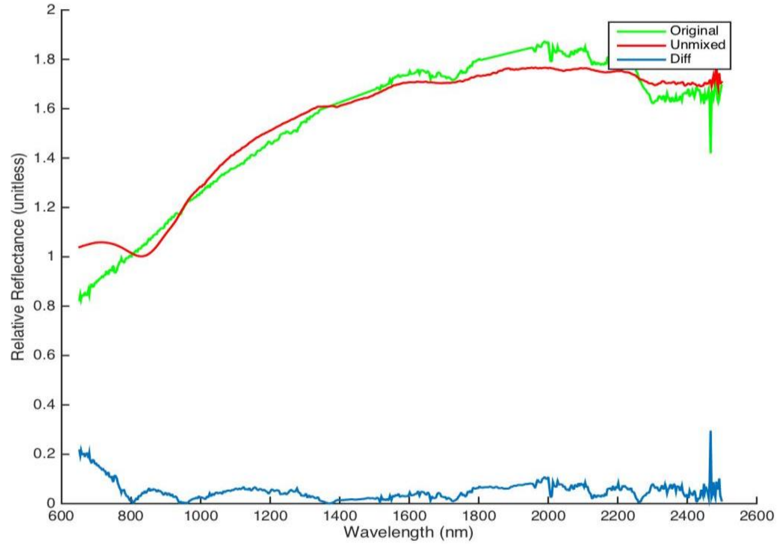


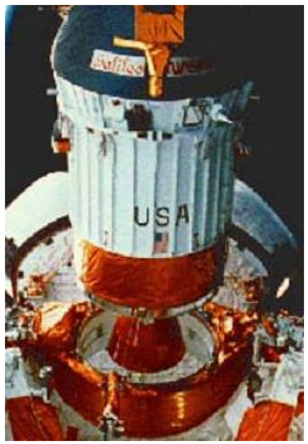
Error 10-13%

SSN	Central Wavelength (nm)	FWHM (nm)	Central Wavelength model (nm)	FWHM model (nm)
ssn08476	1690	90	1738	23
ssn08476	2150	58	2176	35
ssn08476	2310	86	2292	47
ssn08476	2450	31	2370	23

Results: IUS (2)

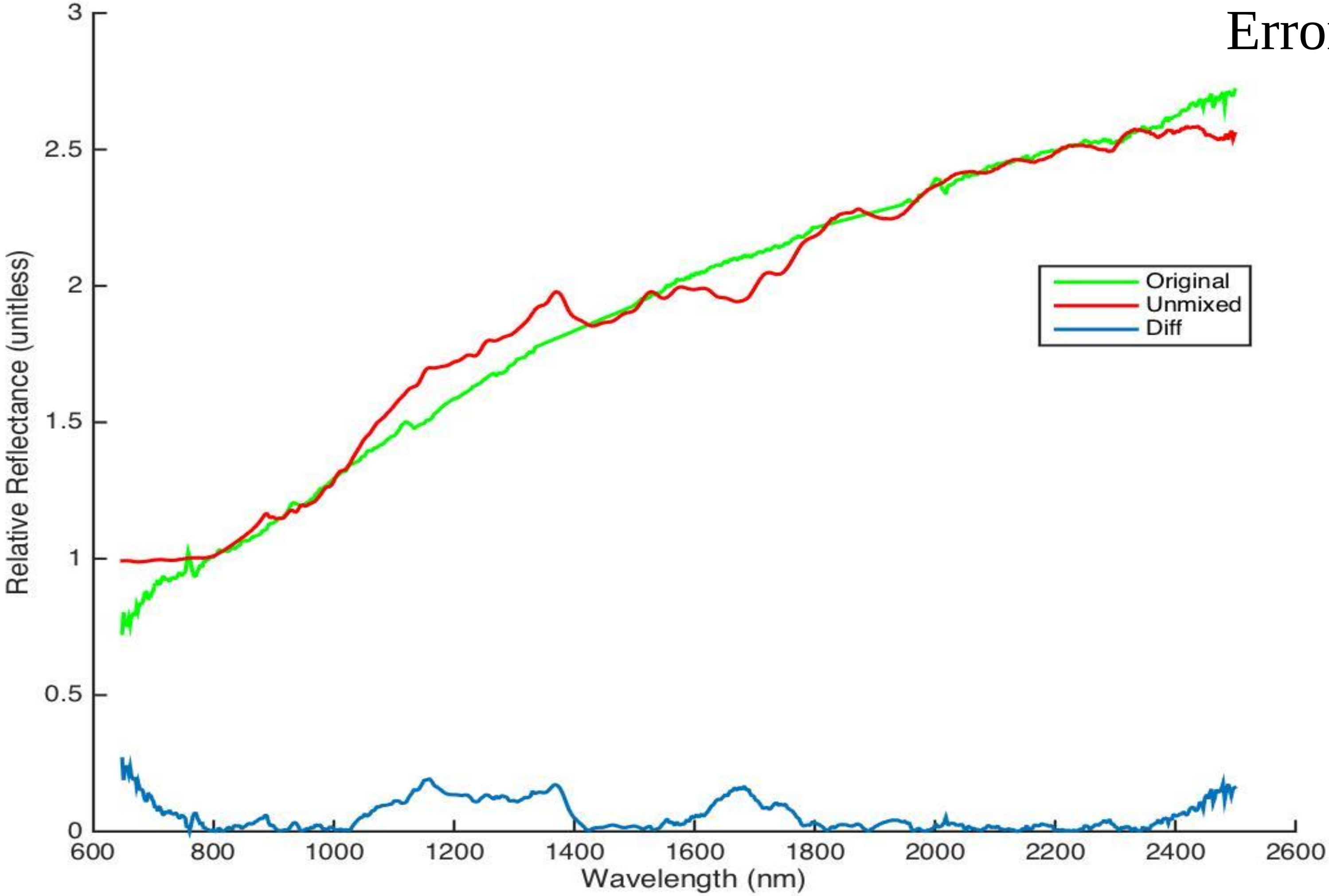




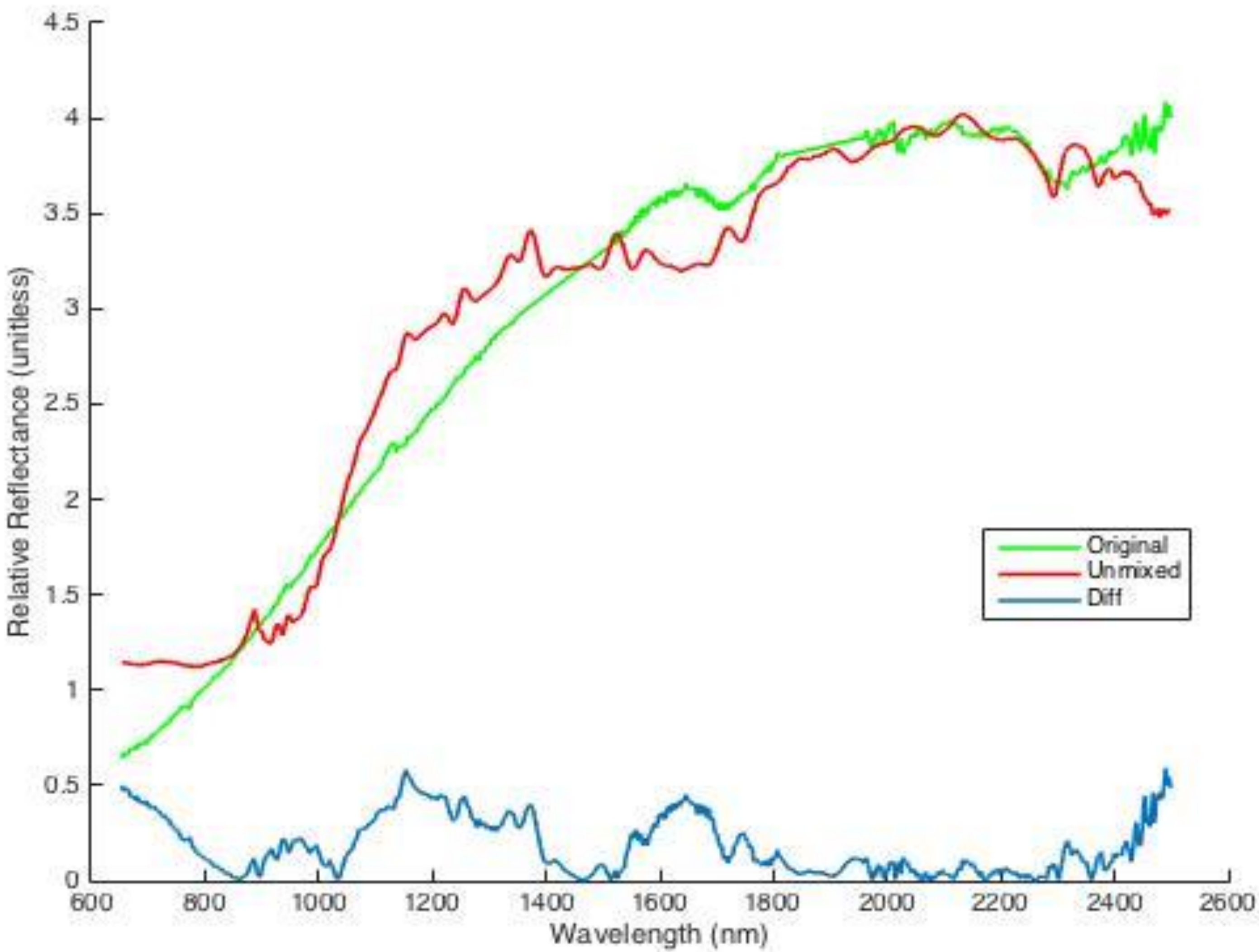


Results: Titan Debris

Error 5%



Results: Ekran 2 Debris



Error 7%

Results: Materials in General

SSN	Common Name	Materials Found	%error
08476	SATCOM 1	Solar Cell, Aluminum	9%
08832	TITAN 3C TRANSTAGE DEB	Solar Cell, Aluminum	7%
11669	OPS 6393 (FLTSATCOM 3)	Solar Cell, Aluminum	6%
11964	GOES 4	Solar Cell	5%
12855	SBS 2	Solar Cell, MLI, Kapton, White paint, Exp white paint, Inconel	1%
13984	SATCOM 1R	Solar Cell, MLI, Kapton, White paint, Inconel	2%
14234	ARABSAT 1DR (TELSTAR 3A)	Solar Cell, MLI, Alumized Kapton, White paint, Inconel	2%
14421	INTELSAT 507	Solar Cell, Aluminum	5%
15385	SPACENET 2	Solar Cell, MLI, Kapton, White paint, Exp white paint, Inconel	2%
15826	TELSTAR 303	Solar Cell, MLI, Kapton, White paint, Exp white paint, Inconel	1.5%
19550	IUS R/B (2)	Exp White paint	7%
20570	NEWSAT-1 (PALAPA B2R)	Solar Cell, MLI, Aluminum, Kapton, White paint, Exp white paint, Aluminized Beta Cloth	1%
21641	IUS R/B (2)	Exp White paint	8%
21648	COSMOS 2054 DEB	Solar Cell, MLI, Kapton, White paint, Exp white paint, Inconel	2%
22316	IUS R/B (2)	White paint, exp white paint	3%
23615	IUS R/B (2)	Aluminum, exp white paint	5%
25000	TITAN 3C TRANSTAGE DEB	Anodized Aluminum, Solar cell	4%
25126	HGS-1 (ASIASAT 3)	Solar Cell, MLI, Kapton, White paint, Exp white paint, Inconel	4%
25645	SL-12 R/B (2)	Aluminum, Aluminized Kapton, Exposed White paint	3%
29014	EKRAN 2 DEB	Aluminum, Solar Cell	4%

Conclusions/Future Work/Thanks

- **Dominant material found was solar cells**
- **Debris objects had higher error values showing that the model does not contain the materials shown in the remote samples**
- **Differences between the results of an intact spacecraft, rocket body, and debris piece are evident**
  - Spacecraft, both the controlled and non-controlled, show distinct features due to the presence of solar panels, whereas the rocket bodies do not, as expected
  - Signature variations between rocket bodies, due to the presence of various metals and paints on their surfaces, show a clear distinction from those objects with solar panels, demonstrating that one can distinguish most spacecraft from rocket bodies through infrared spectrum analysis.

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Conclusions/Future Work/Thanks

- **Future Work**
  - adding more noise such as surface roughness and space environment effects
  - examining the phase angles in conjunction with the spectra
  - adding more laboratory materials to the model in hopes of more clearly defining the material types of these objects..

- **Special thanks to Bill Golisch and Dave Griep for operating the NASA IRTF and facilitating the collection of the spectral data.**